TRANDUCERS'99 *Category: Late News*
The 10th International Conference on Solid-State Sensors and Actuators, Sendai, Japan, June 7-10, 1999

ELECTROACTIVE POLYMER (EAP) ACTUATION OF MECHANISMS AND ROBOTIC DEVICES

Y. Bar-Cohen[a], S. Leary[a], J. O. Harrison[b], and J. Smith[b]

[a] Jet Propulsion Laboratory, Caltech, MS 82-105, 4800 Oak Grove Dr., Pasadena, CA, 91109-8099, USA, Web: http://ndeaa.jpl.nasa.gov, phone: 818-394-2610, fax 818-393-4057, e-mail yosi@jpl.nasa.gov
[b] Composites and Polymers Branch, NASA LaRC, Hampton, VA, USA

ABSTRACT

Actuators are responsible to the operative capability of manipulation systems and robots. In recent years, electroactive polymers (EAP) have emerged as potential alternative to conventional actuators. These materials have characteristic similarities to biological muscles, making them very attractive once their actuation force is improved. Under a NASA task, a study is underway to develop EAP actuators for planetary applications. Two types of EAP materials are employed including the bending ion-exchange membranes and longitudinally actuated elastomers. Experiments at low temperatures and vacuum showed that the ionic-type EAP responds effectively at cryovac conditions. This capability enabled a series of new potential space applications that are currently being investigated. Some of the devices and mechanisms that are considered include dust wiper and miniature robotic arm with 4-fingers gripper. The EAP dust wiper is developed for the Nanorover, which will be launch to an asteroid in the year 2002 on the joint Japan/USA MUSES-C mission.

INTRODUCTION

NASA is increasingly seeking to operate its telerobotic devices and space mechanisms using efficient miniature actuators that are light, compact and consume low power. Electroactive ceramics (EAC) have been widely used in such mechanisms as ultrasonic motors, inchworms, translators and manipulators. However, they induce small displacements and they are fragile, thus limiting their potential applications. In contrast, EAP materials have emerged as alternative actuators having displacement capability that can be over two orders of magnitude higher than EAC [1]. Further, their response speed is significantly higher than Shape Memory Alloys (SMA), which are also widely used. The authors' are seeking to take advantage of EAP resilience, fracture toughness and property tailorability. Their main attractive feature is the emulation of biological muscles, in dexterity, high toughness, large actuation strain constant and inherent vibration damping. Unfortunately, in terms of force actuation they are still lagging greatly behind EAC and SMA. While the research community is investigating methods of increasing the induced force, efforts are made to employ their current capability. This effort is requiring interdisciplinary effort using expertise in materials science, chemistry, mechanics, electronics, and robotics. The infrastructure of EAP actuators is still lacking some key technologies and capabilities. Once sufficient progress is made, EAP actuators could possibly be developed to assist the mobility of physically impaired handicaps.

EAP AS ACTUATORS

The authors identified two EAP material categories of inducing large actuation strains, which can be used practically. These materials include (a) bending actuators: Ion exchange polymer membrane metal composites (IPMC) [1-3]; and (b) longitudinal actuators: electro-statically activated EAP [1,4]. In parallel to the authors' effort to develop efficient materials, they are seeking to identify robotic and planetary applications for NASA future missions. The IPMC material is critically sensitive to its water content in its porous matrix and it requires protective coating to prevent water loss due to evaporation. A coating method was developed that enabled operation in air for about 4-months. IPMC films were tested at cryogenic temperatures, below Mars conditions, and the results showed significant actuation displacement. This capability is essential for operation at planetary conditions. Two actuation limitations are currently being addressed: (a) low actuation force and (b) lack of compatible sensors matching the strain and flexibility while providing feedback for robotic tasks.

EAP SURFACE WIPER

Lessons learned from the Viking and Mars Pathfinder missions indicate that that such operations can be hampered by dust accumulation, which degrade the mission efficiency with time (particularly, on solar cells and imaging instruments). To remove dust from surfaces one can use a mechanism similar to cars' windshield wipers. Unfortunately, such wipers are power intensive, heavy, cumbersome, and cannot be practical for such tasks as dust removal from individual solar cells. IPMC can ideally suit to such a function of operating as a surface wiper. A simple, miniature, lightweight, low power 30-mm long IPMC film was constructed as a wiper (see Figure 1). The film was activated by 0.3-Hz signals and about 4-V leading to back & forth bending, which exceed $\pm 90^{o}$. The dust removal capability of the bending IPMC films addressed a critical NASA problem and a pair of surface wipers is currently being designed for use on the JPL's Nanorover. This rover is constructed for the mission MUSES-C to an asteroid, which is expected to be launched on a Japanese rocket in 2002. A cooperative effort with the Osaka National Research Institute [3] is currently underway to potentially employ their bending EAP material in this mission.

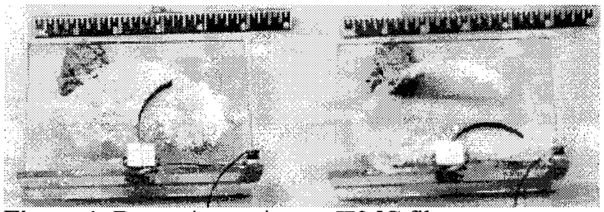

Figure 1: Dust wiper using an IPMC film.

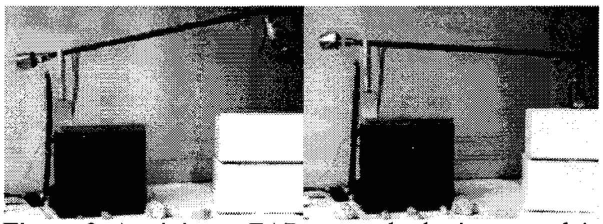

Figure 2: A miniature EAP actuated robotic arm and 4-finder gripper.

MINIATURE ROBOTIC ARM

The availability of EAP actuators that can bend or extend/contract enabled the capability to produce unique robotic devices that emulate the human hand. A robotic arm was developed and computer programmed (see Figure 2). This arm consists of a 5-mm diameter graphite/epoxy rod that was actuated by a longitudinal EAP rope. This rope was connected to the short end of this balanced rod to allow electroactively lower or raise the arm. On the right of the rod, an end effector gripper was mounted having four bending EAP fingers and miniature hooks to secure gripped objects. The longitudinal EAP rope actuated the arm by tilting its balance. The maximum lifting amplitude is determined by actuation strain and the ratio between its connection distance from the pivot point compared to the gripper distance. The longitudinal EAP was used here as the equivalent of human muscle with the exception that it becomes longer under activation. The gripper having 4-fingers grabs and holds objects and thus forms the equivalent of a human hand. The inability of the IPMC films to lift any significant mass was taken into account in this application by avoiding this necessity. The fingers, which have remarkable opening capability, were used to "hug" the samples and grab them by the hooks that were attached at the finger ends. The fingers move back and forth to open and close the gripper similar to a human hand, embracing the desired object and grabbing it. The demonstration of this robotic arm and gripper capability to lift a rock was intended to pave the way for miniature EAP ultra-dexterous and versatile robotic devices. Such devices may be used in future planetary application to conduct in-situ sample collection and manipulation tasks.

CONCLUSION

EAP actuators have numerous advantages that make them attractive to enable unique technologies and capabilities. They are changing the paradigm about the complexity of robots - where they can be used to construct robots without the need for any of the conventional components like motors, gears, bearings, screws, etc. EAP's actuation characteristics resemble biological muscles, however while they can induce large displacements their force actuation is still relatively low. The challenge to the research community is to bring the force capability to the level that can arm wrestle with humans and win.

6. ACKNOWLEDGEMENT

The research at Jet Propulsion Laboratory (JPL), California Institute of Technology, was carried out under a contract with National Aeronautics and Space Agency (NASA).

REFERENCES

[1] Y. Bar-Cohen, S. Leary, M. Shahinpoor, J. O. Harrison, and J. Smith, "Flexible low-mass devices and mechanisms actuated by Electroactive Polymers," Paper 3669-38, Proc. of the 6th SPIE Ann. Internat. Symp. on Smart Mat.&Struct, Newport Beach, CA, USA March 1-2, 1999, , (to be published).

[2] M. Shahinpoor, Y. Bar-Cohen, J. O. Simpson and J. Smith, "Ionic Polymer-Metal Composites (IPMC) as Biomimetic Sensors, Actuators & Artificial Muscles-A Review," Smart Mat. & Struct. J., Vol. 7, No. 6, pp. R15-R30, (1998)

[3] A. Yoshiko, A, Mochizuki, T. Kawashima, S. Tamashita, K. Asaka and K. Oguro, "Effect on Bending Behavior of Counter Cation Species in Perfluorinated Sulfonate Membrane-Platinum Composite," Poly. for Adv. Tech., Vol. 9, pp. 520-526 (1998).

[4] R. Kornbluh, R. Pelrine & Joseph, J., "Elastomeric dielectric artificial muscle actuators for small robots," Proc. of the 3rd IASTED Internat. Conf., Cancun, Mexico, June, 14-16, 1995.